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A Compton suppressed detector multiplicity trigger based digital DAQ for gamma-ray spectroscopy

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ABSTRACT

The development of a digitizer based pulse processing and data acquisition system for γ-ray spectroscopy with large detector arrays is presented. The system is based on 250 MHz 12-bit digitizers, and is triggered by a user chosen multiplicity of Compton suppressed detectors. The logic for trigger generation is similar to the one practised for analog (NIM/CAMAC) pulse processing electronics, while retaining the fast processing merits of the digitizer system. Codes for reduction of data acquired from the system have also been developed. The system has been tested with offline studies using radioactive sources as well as in the in-beam experiments with an array of Compton suppressed Clover detectors. The results obtained therefrom validate its use in spectroscopic efforts for nuclear structure investigations.

1. Introduction

The advent of digitizer based pulse processing and data acquisition systems (DAQ) in nuclear spectroscopy has ushered an era of fast, compact and efficient experimental setups associated with the large detector arrays across the globe. These facilities are capable of handling increased event rates, typically encountered in such arrays at the contemporary heavy-ion accelerators, and record time-stamped list mode data that is subjected to the customary data reduction procedures and analysis [1]. In view of their efficacy in processing higher event rates, it is often alluring to operate these systems in a triggerless mode wherein one records all live events irrespective of any condition on the detector multiplicity or otherwise. Such operation is perceived to facilitate the user with greater flexibility of implementing the prerequisites of an acceptable event during the offline analysis.

Nuclear structure investigations using γ-ray spectroscopy, however, is largely based on time correlated coincidence measurements. The time correlation between different γ-rays recorded by individual detectors in the setup goes a long way in establishing the level structure of the nuclei of interest. The same is characterized by the energy, spin-parity and lifetime of the levels along with energy, multipolarity and electromagnetic character of the connecting transitions. Such measurements typically follow a nuclear reaction, aimed at populating the residue of interest, wherein an ensemble of nuclei, each with its characteristic deexcitation, is produced. Obviously, numerous γ-ray transitions shall be emitted from this agglomeration and the only mean to ascribe a particular one to a specific nucleus is its coincidence relationship with the other correlated transitions as encoded in the γ–γ matrices, the γ–γ–γ cubes and the γ–γ–γ–γ hypercubes, constructed out of the acquired data for subsequent analysis. It is understood that in the absence of any coincidence requirement on the data acquisition, the events recorded would predominantly consist of a single γ-ray transition recorded in a detector without any consideration for time coincidence with any other emission detected in a different detector. Such time uncorrelated singles, while consuming a substantial storage space, are of limited usage and are often discarded during the data reduction (into matrix, cube and hypercube) exercise. Further, while the coincidence between different detectors

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of an array facilitate inferring the excitation pattern of the nuclei of interest, anti-coincidence, also based on timing correlation, between a (HPGe) based γ-ray detector and the respective (scintillator based) anti-Compton shield (ACS) aid in reducing the Compton background. A triggerless system may opt to acquire signals independently from the HPGe and the corresponding ACS and impose the aforementioned anti-coincidence condition, offline. Such a philosophy, once again, will warrant a huge primary dataset, particularly owing to the more efficient scintillator based ACS. A substantial part of this data will need to be rejected from the requirement of Compton suppression that necessitates exclusive signal from the HPGe with no coincident signal from the corresponding ACS. It can thus be stated that while the triggerless mode of acquisition provides flexibility of implementing trigger conditions offline and optimize the same, the overhead on the data storage as well as in the processing time and complexity is significant. This is particularly relevant in the context of a typical contemporary γ-ray spectroscopy measurement wherein, owing to substantial (~1000 mb) fusion-evaporation reaction cross-section and large array of detectors, even the γ–γ coincidence rate can be ~6000–7000 events/s with individual (composite) detectors counting at ~20000–25000 counts/s. A triggerless acquisition can be envisaged for an experimental setup of γ-detector array in conjunction with ancillary detectors (charged particle, neutron etc.) to facilitate offline selectivity of reaction channels and/or energy levels of interest. But for a setup of only γ-ray detectors, as in the present case, it is known that the Compton events would be the undesired ones and have to be rejected. Such rejection, if implemented in the hardware trigger, is expected to counter the aforementioned issues with the triggerless mode.

In the light of the aforesaid arguments, it is thus desired that the fast processing characteristics of the digitizer based system may be combined with a hardware implementation of a trigger condition so as to acquire useable events where from the intended physics information can be extracted. The hardware trigger incorporates the conditions conventionally practised in the analog pulse processing with electronic circuitry of NIM/CAMAC standards and is primarily based on the (user) chosen multiplicity of Compton suppressed detectors. The present paper reports the development of such a system along with its validation using an array of Compton suppressed Clover detectors.

2. DAQ hardware and experimental setup

The principal component of the hardware for this new system is the Pixie-16 Rev-F 12-bit 250 MHz digitizer module manufactured by the XIA LLC, USA. The modules are housed in 14-slot 6U PXI crates from WIENER, Germany. The system is controlled through PXI-PCI8366 controller, the PXI card of which is located at Slot # 1 of the chassis and connected to the host computer (with the PCI card) through a fibre optic cable. Each Pixie-16 module has 16 input channels to accept the preamplifier signals from the Clover and the ACS, as detailed hereafter. A Clover detector, as is well known [2], is a composite detector with four HPGe crystals each with a preamplifier card that provides signal output for the respective crystal. The 16 channels of a Pixie-16 module are grouped in 4 groups as Channels#0–3, Channels#4–7, Channels#8–11 and Channels#12–15. Of these, each of the first three (0–3, 4–7, 8–11) groups can accept four preamplifier signals corresponding to a Clover detector. The first three channels of the fourth group, Channel#12, Channel#13 and Channel#14 is respectively designated to accept the preamplifier signal of the ACS corresponding to the Clover being fed in Group 1 (Channels# 0–3), Group 2 (Channels# 4–7) and Group 3 (Channels# 8–11). This implies, for instance, if the four signals from a Clover detector is input to Channels# 0–3, the corresponding ACS would be input to Channel#12 and likewise for the other two Clovers in the Group 2 and the Group 3 channels of the module. Thus, a Pixie-16 module, operated in this mode, can support 3 Compton suppressed Clover detectors.

Fig. 1 illustrates the components of the Pixie-16 module, manufactured by XIA LLC. Each of the aforementioned group of signals is processed by one signal processing FPGA (Field-Programmable Gate Array) in the Pixie-16 module for pulse detection via fast trigger, pulse height sampling, pile-up rejection and data capture and recording. The fast triggers, extracted from the digitized preamplifier signals of the individual crystals of a Clover, generated in the four signals processing FPGAs for the 16 channels of a module is sent to a Main FPGA for generation of trigger conditions and the same can be sent back to each signal processing FPGA, for validation of an event. Further, the fast triggers from one Pixie-16 module can be shared with other modules in the PXI crate through the backplane. There are more than 100 backplane bus lines that are connected to each slot of the 14-slot chassis housing the system. The main FPGA on each PIXIE-16 module in the slots can access those backplane bus lines and thus triggers can be distributed and shared among all of the PIXIE-16 modules in the chassis. Thus a system-wide trigger decision can be generated based on fast triggers from all the detector channels in a large array and such a trigger can be subsequently used as a global validation signal for the individual channels. The flow of signals in Pixie-16 module is elaborated in the next section.

The experimental facility used for testing the digitizer based DAQ system was the VEcc array for NUclear Spectroscopy (VENUS) [4], set up at the K130 cyclotron of the Variable Energy Cyclotron Centre (VECC) in Kolkata (India). During these tests the VENUS consisted of six Compton suppressed Clover detectors positioned at 45° (1 detector), 55° (1 detector), 90° (2 detectors) and 150° (2 detectors) with respect to the beam direction, in the median plane ($\phi = 0°$). The distance of the target position from the end cap of the detectors was 26 cm. Thus, two Pixie-16 modules, each supporting three Compton suppressed Clover detectors, were used for data acquisition. The photographs of the VENUS array and the digital DAQ are shown in Fig. 2.

3. Trigger logic and firmware

The formation of event trigger in the digitizer based DAQ system can be perceived as a two-step process. The first being the extraction of a Compton suppressed logic signal from the individual Clovers followed by the implementation of time overlap between these signals for (detector) multiplicity based trigger generation, duly vetoed by the presence of undesired (system busy etc.) signals.

The build up of the Compton suppression logic from individual Clovers is illustrated in Fig. 3. The fast triggers, extracted from the digitized preamplifier signals of the four crystals of the Clover, are OR-ed and the resulting (logic) signal is bifurcated. One part is set to a width of ~50 ns while the other is delayed with respect to the first one, by ~100 ns, and stretched to a width of ~1 μs. The NOT version of the latter, that is AND-ed to the former, facilitates in restricting the time jitter on the OR signal from the Clover. The same is then delayed by ~50–100 ns, as required, to ensure a definitive overlap with a wider (~300 ns) logic signal from the corresponding ACS. The signal from the Clover is then AND-ed with the NOT version of that from the respective ACS, for anti-coincidence, and the resulting signal represents the Compton suppressed logic output of the corresponding Clover.

The Compton suppressed logic outputs of the individual Clovers are then checked for time overlap for generation of the multiplicity output. The same is vetoed by the busy output of the DAQ system and the (uncorrelated) singles. The resulting signal represents the master trigger for acquisition of data in all the active channels of the system. The width of the master trigger was optimized to 600 ns for the subsequent offline and in-beam tests, reported herein. The width of the global trigger could be further reduced but was set slightly on the higher side in order to accommodate any possible jitter as well as coincident overlap occurring on the edges. And, given that the recorded data include the time stamp (discussed subsequently) of an event, the stringency of timing correlation can always be increased offline. The block diagram corresponding to the generation of the master trigger is depicted in Fig. 4. In order to further ensure that only those channels that contribute in the generation of the master trigger have

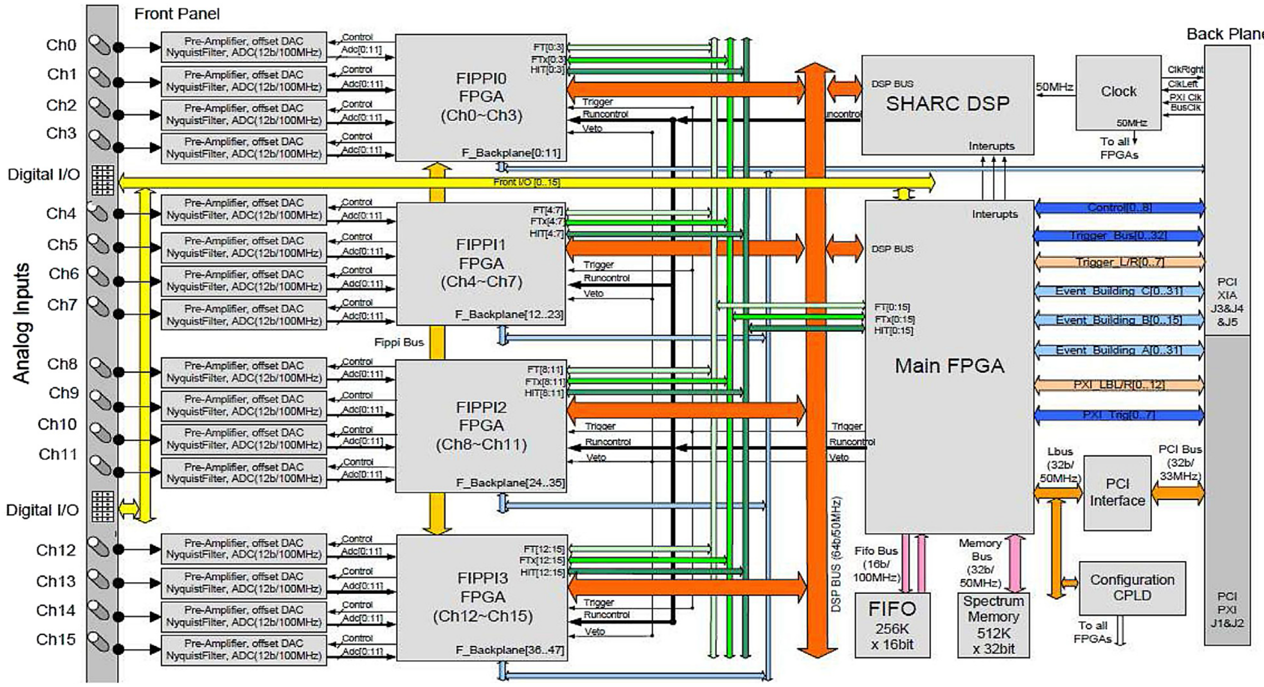

Fig. 1. (Colour online) Block diagram of the Pixie-16 module manufactured by XIA LLC [3].

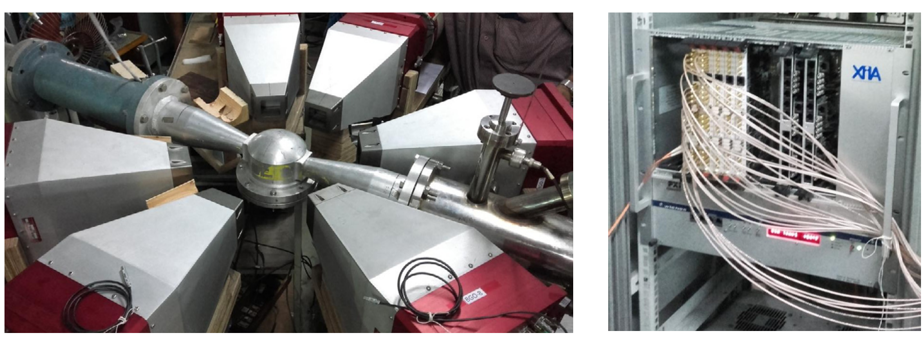

Fig. 2. (Colour online) The VENUS array [4] at the K130 cyclotron in VECC, Kolkata and the DAQ system based on Pixie-16 digitizer modules. The distance of the target position from the end cap of the detectors was 26 cm.

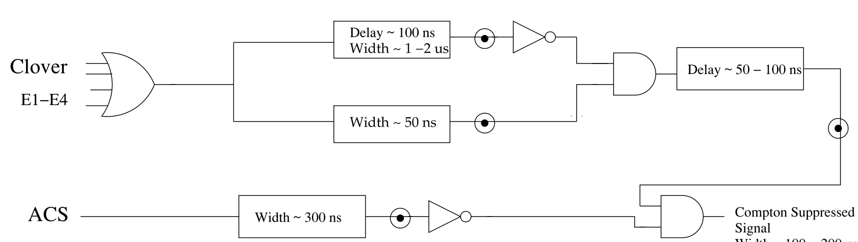

Fig. 3. Schematic representation of generation of Compton suppressed logic signal in the digitizer based DAQ system. E1–E4 represents the four fast triggers extracted from the (four) digitized preamplifier signals of each Clover detector.

their data recorded and no other channels, that may have an accidental overlap with the master can record their data, a scheme for individual channel gates is also implemented in the present system (Fig. 4). These individual gates are extracted from the overlap of the delayed channel fast triggers, delayed Compton suppressed logic signal of the respective Clovers and the master trigger. The delays applied on the individual channel triggers (EN-1, EN-2...in Fig. 4) and the individual Compton suppressed Clover signals (C1...CN in Fig. 4) are meant to compensate for the delay in the generation of the master trigger from the channel fast triggers.

Fig. 5 depicts the actual flow of signals in the signal processing FPGA (FiPPI in Fig. 1) of the Pixie-16 module [3]. The input analog pulse is first digitized by the ADC, following which it enters the signal processing circuitry of the FiPPI. The digitized data stream is fed into two branches. One is the fast filter that is generated for forming multiplicity groups in the system FPGA and can be stretched up to 32.76 μs long and delayed up to 1.02 μs by the delay FIFO (128 deep, 1-bit wide). The second branch of the digitized pulse is fed into the delay FIFO (256 deep, 16-bit wide) that could be used to compensate for the delay between the Pixie-16 fast triggers and the external trigger. The latter branch of the

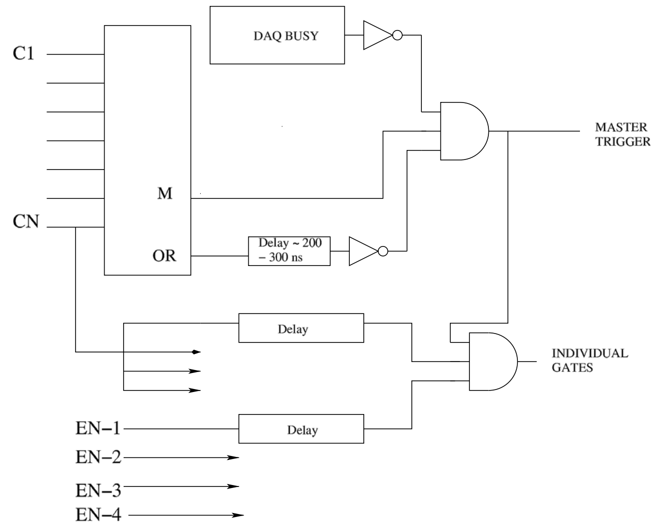

Fig. 4. Schematic representation of generation of master trigger and individual channel trigger for data acquisition. C1..CN represent the Compton suppressed signals, generated as per the scheme in Fig. 3, from individual Clovers. M represents the multiplicity output corresponding to the number of individual Compton suppressed Clover signals in coincidence. An individual gate is generated from the AND of the master trigger, delayed corresponding Compton suppressed Clover signal (C1, for example) and delayed corresponding channel fast trigger (EN-1, for example). Thus, each individual Compton suppressed Clover signal (C1...CN) as well as each of the channel fast triggers (EN-1, EN-2, ...) are delayed for generation of the individual gates.

digitized data stream passing through the delay FIFO is then branched into, (i) the energy filter for peak height sampling; (ii) trigger filter for fast trigger detection and pile-up inspection; (iii) a capture FIFO (1024 deep, 16-bit wide) for incorporating the delay between the input analog pulse and the possible external trigger or veto signals so that the digitized data can be directly streamed into the trace Dual Port Memory (DPM) when the pulse is validated; and (iv) the CFD circuitry where a CFD trigger is generated to latch the timestamps. The Control Logic in FiPPI accepts the local fast trigger, CFD trigger, veto signal and external triggers, and decides when to stream waveform data into the Trace DPM and to write the event information in the Header DPM. The DSP polls the status of the DPMs through the Status Registers and moves event data into the External FIFO through the System FPGA. The delay in the FPGA can be implemented as a series of registers or as a FIFO and the timing of such a delay is deterministic and is functioned in exactly the way it is designed. The trigger logic described in Fig. 4 is implemented in the System (Main) FPGA that has access to the fast triggers not only from its own 16-channels but also from all other Pixie-16 modules in the chassis. The delays and widths mentioned in the preceding discussions have a granularity of the FPGA clock period (8 ns). It may, however, be noted that these delays and widths actually control the generation of the global trigger that only validates an event.

The aforesaid trigger generation logic has been routinely pursued in the analog pulse processing electronics associated with large arrays of γ-ray detectors such as the Indian National Gamma Array (INGA) [5]. However, to the best of our knowledge, this is the maiden instance of implementing such trigger logic in the firmware running on a digitizer system. The system accepts the preamplifier pulses from the (Clover) detector as input and performs the aforementioned processing to validate or negate the detected events. Delays and widths of signals are adjusted through a GUI provided by the manufacturer (XIA LLC) [3] for setup, control and operation of the system. A front-panel har-link connector from HARTING, with six configurable output pins, is provided on each Pixie-16 module to access different signals, defined through the GUI, that can be displayed on a digital/mixed signal oscilloscope for

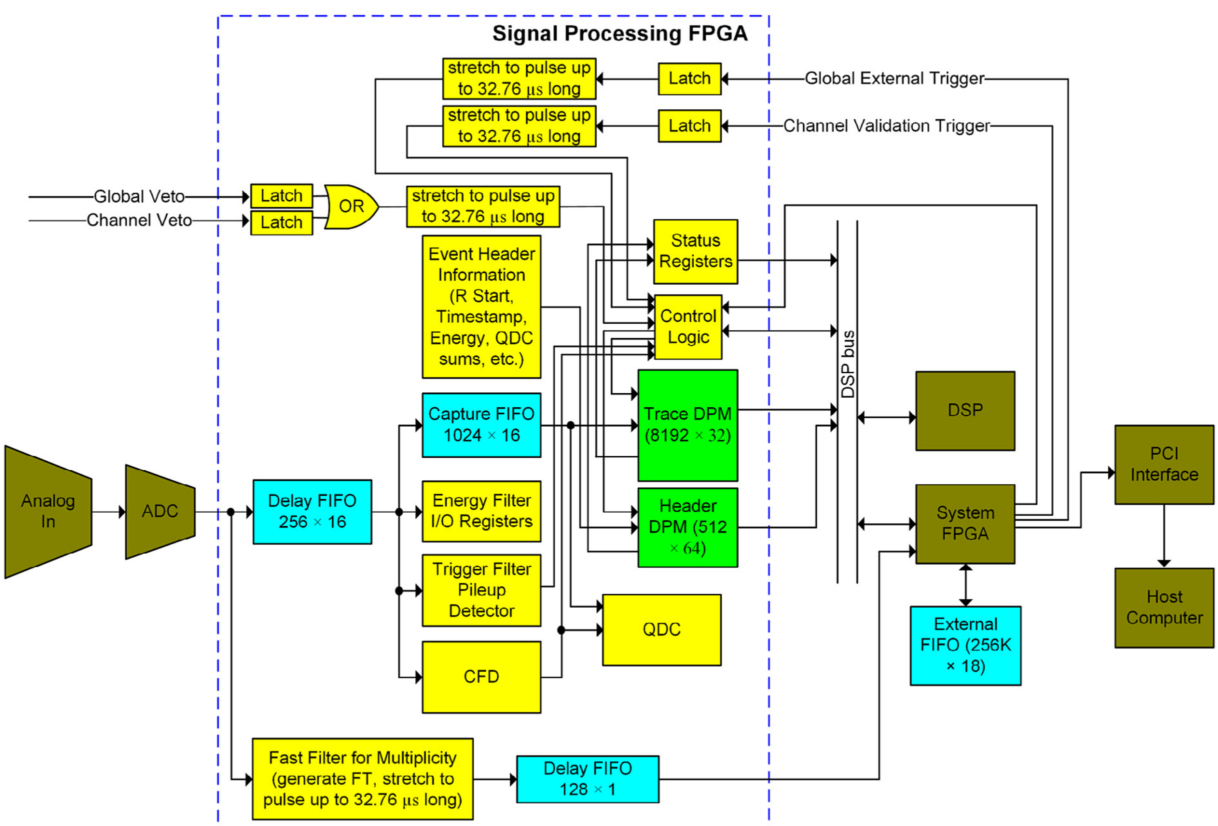

Fig. 5. (Colour online) Signal flow in the Pixie-16 signal processing FPGA [3].

setup and troubleshooting. It is expected that the data acquired herefrom would conform with the user chosen trigger based on the multiplicity of Compton suppressed detectors and can be completely used for the subsequent analysis.

4. Data reduction and analysis

The data in γ-ray spectroscopy endeavours, for nuclear structure studies, is typically acquired in the list mode format which represents an event-by-event record of the detectors firing (detecting) along with the respective energies and timing of the detected pulses. An event represents an instance of fulfilment of the user defined (master) trigger condition which, in the contemporary spectroscopic measurements, is typically based on a specified multiplicity of detectors firing in coincidence (within a time window ~100 ns). In the present digitizer system, for each channel (one crystal of the Clover detector) that has detected a pulse in an event, there are four 32-bit words written in the data [3] wherein the information of primary significance, used in the subsequent reduction and analysis, are as follows. The first is the identity of the detector (channel) that has fired and the same is extracted from the Slot ID and the Channel Number recorded in the data. The next quantity of interest is the timing of the detected pulse that is determined from the 48-bit time stamp and the CFD value, as detailed subsequently in this section. And finally another information of importance is the energy of the detected pulse, that is read-out from the data. The data also records a flag for the pile-up events and facilitates their elimination in offline analysis. Any digitizer based DAQ system, such as the present one, provides an option for recording of the trace of the input pulse as well. Obviously this, if enabled for a multi-Clover array, would lead to an unrealistically large dataset, most of which is not required for the intended purpose (γ-spectroscopic measurements based on detector multiplicity) and thus the recording of the trace is not enabled in the present tests.

The determination of the time stamp, mentioned above, proceeds as follows. In the present system, two fast triggers are generated from the input preamplifier pulse (output of the detector) through application of a trapezoidal filter (fast filter) [6,7]. One of these is used for multiplicity computation and generation of master and channel triggers while the other for local signal processing such as pile-up detection and peak height sampling. The time stamp of a validated pulse, counted with respect to a global clock that is initialized at the commencement of a new run (acquisition), is latched at the point of crossing of the (user defined) threshold on the leading edge of the respective fast filter output. In the 250 MHz board, the time stamp is counted in 125 MHz clock ticks that implies the minimum gap between two consecutive time stamps is 8 ns. The fast filter (FF) response of a digitized waveform is given by,

$$FF[i] = \sum_{j=i-(FL-1)}^{i} Trace[j] - \sum_{j=i-(2*FL+FG-1)}^{i-(FL+FG)} Trace[j]. \tag{1}$$

FL and FG being the fast length and the fast gap parameters of the trapezoidal filter applied on the input pulse to generate the fast triggers. (In the current setup they were chosen to be 100 ns.) This leading edge time stamp can be optionally modified by enabling (through GUI) the CFD. The CFD value is calculated as,

$$CFD[i + D] = FF[i + D] * (1 - w/8) - FF[i] \tag{2}$$

where D is the CFD delay length and w is the CFD scaling factor. The D was optimized to 64 ns for Clovers, 16 ns for ACS and w to 2 in the current tests. The Zero Crossing Point (ZCP) of the CFD is determined from the criterion, CFD[i] ≥0 and CFD[i + 1] < 0 and the final CFD value, to be recorded in the data, is calculated using

$$CFD = \frac{CFDout1}{CFDout1 + |CFDout2|} * 16384 \tag{3}$$

where CFDout1 and CFDout2 are the CFD values just before and just after the ZCP, respectively. The total time stamp, in presence of the CFD, is given by,

$$((TIME\_LO + TIME\_HI * 2^{32}) * 2 - TRIGGER\_SOURCE + CFD/16384) * 4\ \text{ns} \tag{4}$$

where, TIME_LO represents the 32-bit second word of the channel record, TIME_HI is the first 16-bit of the third 32-bit word, the TRIGGER_SOURCE indicates if the CFD ZCP is in the even (0) or odd (1) clock cycle and generation of the CFD value, used in Eq. (4), has already been discussed above. Further, if the CFD threshold is set too high or even otherwise, it may so happen that a particular channel does not register a CFD trigger for certain period. In that case, on not finding a CFD trigger for 32 clock cycles in a particular channel, the system would force one, with an indication (value 1) in the bit # 31 of the third 32-bit word that this is a forced CFD trigger and different from the regular ones. The time stamp for each channel record, calculated using Eq. (4), is eventually used to identify the detectors (Clover crystals) participating in an event during the course of data reduction, as detailed in the following section.

A set of codes, IUCPIX, has been developed for reducing the acquired data from the digitizer based system into reduced formats, such as γ–γ matrix and γ–γ–γ cube, encoding the coincidence and correlation information between the observed γ-rays that facilitates the investigation of level structure of the emitting nuclei. The digitizer based system generates separate list mode data files, in the format detailed in the previous section, for each active module in the crate. The first step of data reduction is time sequencing the event records in these individual data files. It may be noted that individual module files generally come time sequenced in events during acquisition but, at times owing to the count rates, may have records that are out of the usual ordered ascension. Thus the individual files are initially processed to perfect the time sequencing of the event records. Following this, the data files from individual modules are merged to produce a common file wherein the events, though acquired in different modules, are sequenced in a common order of increasing time stamp value. A code to check the sequencing in this resulting file at the end of the process has also been implemented. The common time merged data files are then subjected to the standard procedures practised in the data analysis following γ-ray spectroscopic measurements using a multi-detector array. The individual channels of the modules, corresponding to the crystals of the Clover detectors in the array, are gain-scaled to a common calibration of the pulse height in ADC units. Energies recorded in multiple crystals of the same Clover within one event are added up, representing a time correlated sum, to produce the addback energies. These are used to generate two-dimensional γ–γ matrices, either symmetric or angle dependent, and γ–γ–γ cube, for subsequent analysis. In the present work, an event in the two and higher fold coincidence data is defined by a time window of 200 ns. That is, with respect to the first crystal (channel) record in a data file, all subsequent records in the time ordered sequence, with time stamp values ≤200 ns of the first record are treated to be in coincidence and ascribed to one event. The first channel with time stamp beyond this 200 ns window becomes the reference for deciding the contributing channels for the next event. Likewise the events are sorted in sequence for the entire data file to construct the spectra, matrices and cube. It might be argued that the time window for correlation between the crystals of a clover detector and that for two different clovers are identical in this scheme and might adversely impact the addback process. The latter because the addback procedure aims to add up the energy depositions of a single γ-ray in the individual crystals of a clover detector, owing to Compton scattering, which is expected to have a tighter time correlation than the clover–clover coincidence. Making the addback time window liberal might lead to fictitious energies resulting from the sum of uncorrelated γ-rays detected in different crystals of the same clover. However, it is known that such events are

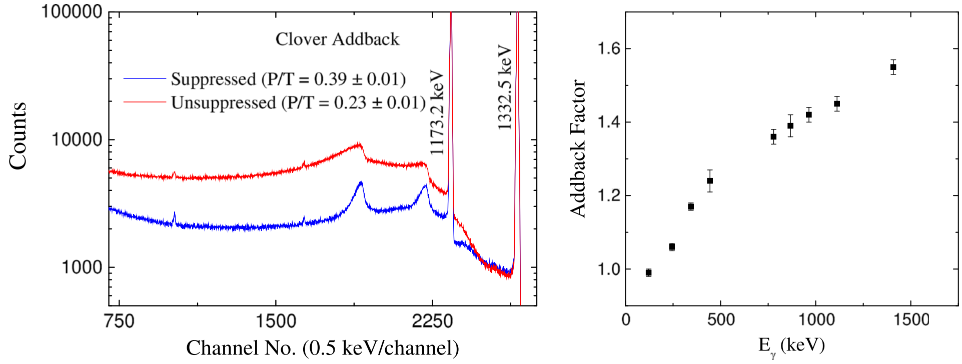

Fig. 6. The left panel illustrates a comparison between the Compton unsuppressed and the suppressed spectra for a typical Clover detector in the present setup with the digitizer based data acquisition system. The right panel depicts the variation of addback factor with incident γ-ray energy for a typical Clover in the present array. These characterization parameters, with their similarity with those acquired with conventional pulse processing electronics, validate the use of the digitizer based system for spectroscopic pursuits.

quite rare, particularly in the distant geometry of the present experimental setup, and can, at best, feature as an insignificant part of the background.

The reduced data is analysed using the standard RADWARE [8] package. The results from this analysis that validate the use of the present system for γ-ray spectroscopy measurements, is presented in the next section.

5. Performance results

The first set of tests for validating the performance of the present system was carried out offline using standard radioactive sources such as ^{60}Co and ^{152}Eu. Typical characteristics indicating the performance of a Compton suppressed Clover detector were extracted therefrom. These include the energy resolution of the detectors, quality of Compton suppression represented by the peak-to-total ratio and addback factor of the Clover detector. The energy resolution of the detectors at the 1332.5 keV peak of the ^{60}Co source was found to be ∼2.2–2.4 keV commensurate with the acceptable limits. The peak-to-total (P/T) ratio, defined as ratio of the sum of net peak (1173.2 and 1332.5 keV) areas in the spectrum of ^{60}Co radioactive source to the total counts in the same spectrum for energies from 100 keV to 1350 keV, was found to be 0.39 ± 0.01 for the Compton suppressed Clovers operated in addback mode and 0.23 ± 0.01 for the corresponding unsuppressed configuration. Typical suppressed and unsuppressed Clover spectra, from the present setup, is illustrated in Fig. 6. The variation of the addback factor, that is defined as the ratio of the area of a γ-ray peak in the addback spectrum to that in the sum spectrum of individual crystals, as a function of the incident γ-ray energies, was studied for the Clovers in the present setup using a ^{152}Eu radioactive source. Typical plot obtained from the exercise is depicted in Fig. 6. The value of the addback factor is ∼1.5 around 1 MeV and complies with the expected value obtained with analog (NIM/CAMAC) pulse processing electronics [2].

Further, the system was used in an in-beam experiment wherein the level structure of the ^{117}Sb nucleus was investigated following the reaction ^{115}In$(\alpha, 2n)$ at E_{lab} = 28 MeV. The target was 4 mg/cm^2 of natural In foil with abundance of ^{115}In isotope ∼96%. The detection system, as mentioned previously, was the VENUS array consisting of six Compton suppressed Clover detectors. The two and higher fold coincidence events were acquired at the rate of 1000–1300 events/s and a total of ∼500 million such events were collected in the data. The typical event profile therein is illustrated in Fig. 7 and indicates, as desired, an emphatic preponderance (∼98%) of γ–γ coincident events with trigger set on detector multiplicity ≥2. As a comparison, Fig. 7 also illustrates the event profile acquired with a trigger on multiplicity ≥1 (singles). While the proportion of singles in the latter is, obviously, dominant and number of coincidences smaller but, to the merit of the

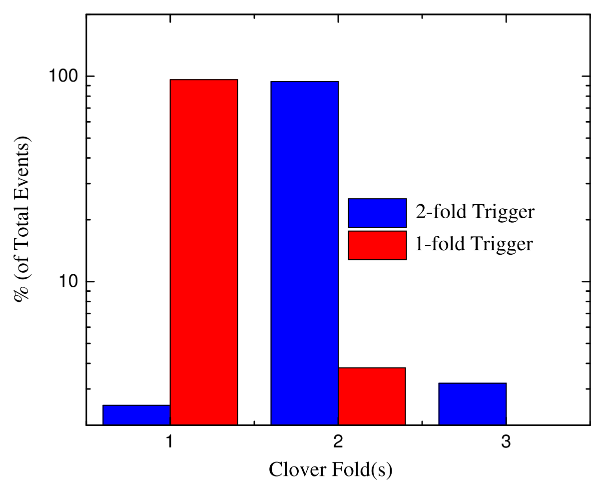

Fig. 7. Representative event profiles of the present in-beam data acquired with six Compton suppressed Clover detectors and detector multiplicity trigger set on one- and two-folds (indicated by the legend).

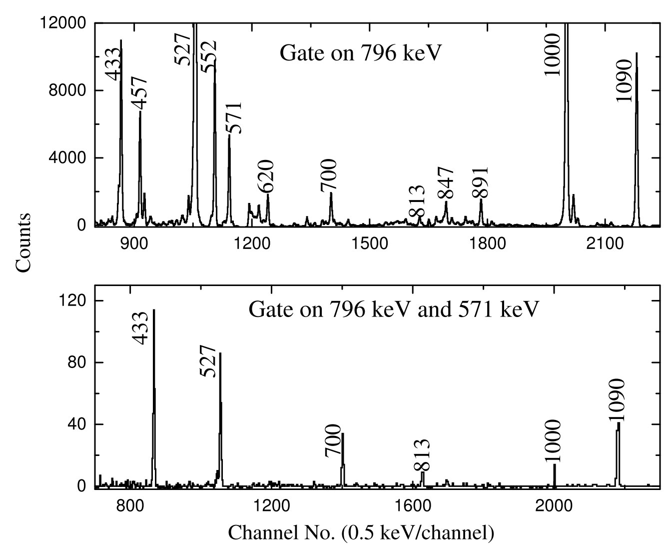

Fig. 8. Typical gated spectra from matrix (upper panel) and cube (lower panel) constructed out of the in-beam data in the present setup. The gates are on the γ-ray transitions of the ^{117}Sb and the peaks in the resulting spectra, belonging to the nucleus (Fig. 9), have been labelled by their respective energies, in keV.

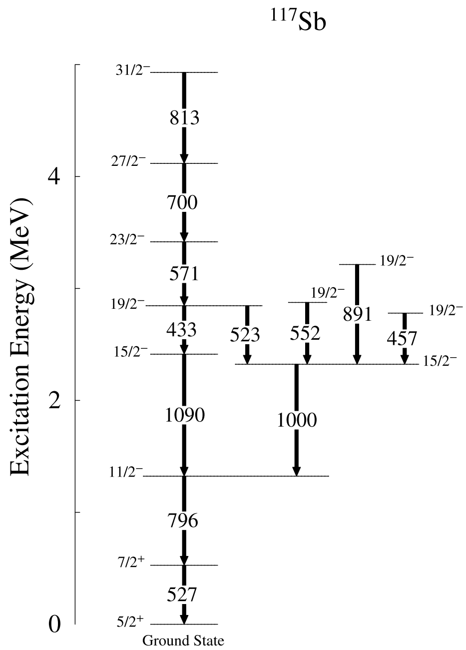

Fig. 9. Partial level scheme of the ^{117}Sb nucleus.
Source: Adopted from Ref. [9].

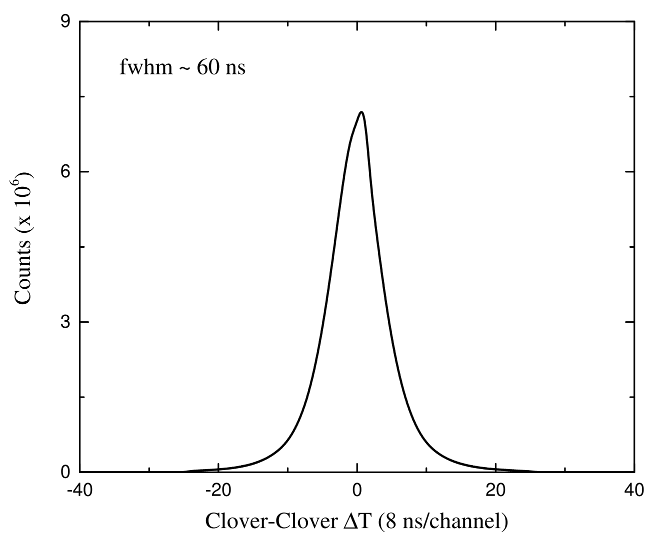

Fig. 10. Typical Clover–Clover timing spectrum obtained from the present in-beam data.

digitizer system, the rate of two- and higher-fold γ–γ coincidences, as it was calculated, is preserved even in the singles trigger. Data reduction and analysis was carried out as per the procedure detailed in the previous section. Fig. 8 illustrates typical gated spectra resulting from γ–γ matrix and γ–γ–γ cube constructed out of the data with gates on γ-ray transition(s) of the ^{117}Sb nucleus. Fig. 9 depicts a partial level scheme of the latter [9], relevant to the observed transitions in the gated spectra. The overlap of the gated spectra with the known level structure of the nucleus validates the use of the present setup for coincidence measurements. The prompt γ–γ timing correlation is represented by the time difference (ΔT) spectrum illustrated in Fig. 10. The fwhm of the ΔT distribution, indicative of the time resolution of the setup, is ~60 ns for the present data and is reasonably close to the same typically obtained with analog pulse processing electronics.

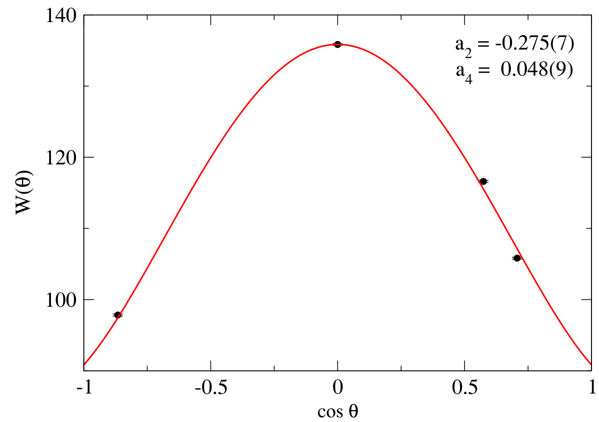

Fig. 11. Fitted angular distribution of the 527 keV transition ($7/2^+ \rightarrow 5/2^+$) of ^{117}Sb.

Of the different measurements carried out with an array of γ-ray detectors, the angular distribution of a transition γ-ray, determined from data acquired with trigger multiplicity $\geq$1 (singles), is of use in identifying its multipolarity wherefrom the spin of the de-exciting state can be inferred. In order to validate the present setup, angular distribution of some of the transitions in ^{117}Sb was carried out and that obtained for 527 keV γ-ray is illustrated in Fig. 11, along with the fit to the experimental data points using [10],

$$W(\theta) = a_0\{1 + a_2 P_2(cos\theta) + a_4 P_4(cos\theta)\}. \quad (5)$$

The nature of the angular distribution and the values of the fitted parameters, a_2 and a_4, are commensurate with the M1/E2 character assigned to the 527 keV transition in the published literature [9].

These measurements described in the preceding text validate the use of the present digitizer based pulse processing and data acquisition system with an array of Compton suppressed γ-ray detectors wherefrom in-beam spectroscopic data can be acquired for nuclear structure studies. The results obtained in the validation checks indicate a data quality complying with the requisites for spectroscopic endeavours.

6. Conclusions

A pulse processing and data acquisition system based on Pixie-16 digitizers from XIA LLC, USA, has been developed for use with large arrays of γ-ray detectors used in spectroscopic pursuits associated with nuclear structure research. Unlike the typical digitizer based data acquisition systems, that operate under a triggerless condition, the acquisition in the current system is triggered by a user chosen multiplicity of Compton suppressed γ-detectors, a philosophy similar in spirit with the logic practised with analog pulse processing electronics albeit using the characteristic fast processing features of the digitizer system. The present system has been used in offline characterization studies with an array of Compton suppressed Clover detectors as well as in in-beam experiments. The results obtained therefrom validate its use in the γ-spectroscopy efforts for nuclear structure research.

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